Increasing Affordability, Energy Efficiency, and Ridership of Transit Bus Systems through Large-Scale Electrification

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2021 DOE Vehicle Technologies Office Annual Merit Review

Project ID #: eems 104

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Overview

Timeline

- Start date: February 2021
- End date: December 2023
- Percent complete: 5%

Budget

- Total project funding
  - DOE share: $1.75 M
  - Contractor share: $0.44 M
- Total funding for FY 2020:$0.65 M
- Total funding for FY 2021:$0.69 M

Barriers

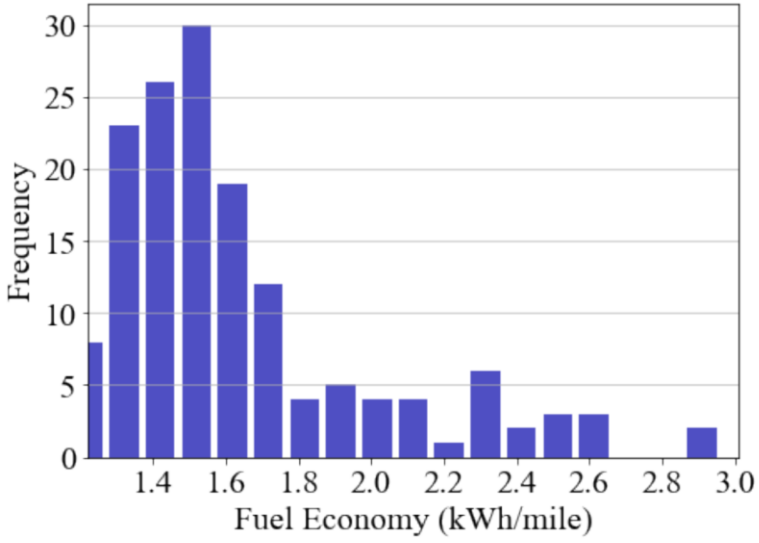
- The need to evaluate the feasibility, reliability, and charging requirements of electric buses
- The lack of a scalable and robust *planning* model that can help transit agencies strategically and effectively deploy electric buses
- The absence of decision support tools brings great *operational* challenges in operating electric buses

Partners

- National Renewable Energy Laboratory (NREL)
- Argonne National Laboratory (ANL)
- Purdue University
- Utah Transit Authority (UTA)
- Tri-County Metropolitan Transportation District of Oregon (TriMet)

Relevance

- **Goal:** The primary goal of the proposed project is to promote the large-scale adoption of electric buses and improve the efficiency and effectiveness of transit bus systems.
- **Challenges:**
  - Develop a holistic modeling framework to address the affordability issue for transit bus electrification.
  - Both the planning and operation tools should be designed to accommodate various uncertainties associated with electrified transit bus systems.
  - Modeling framework should be scalable and consider the potential impact on and constraints of the power grid.

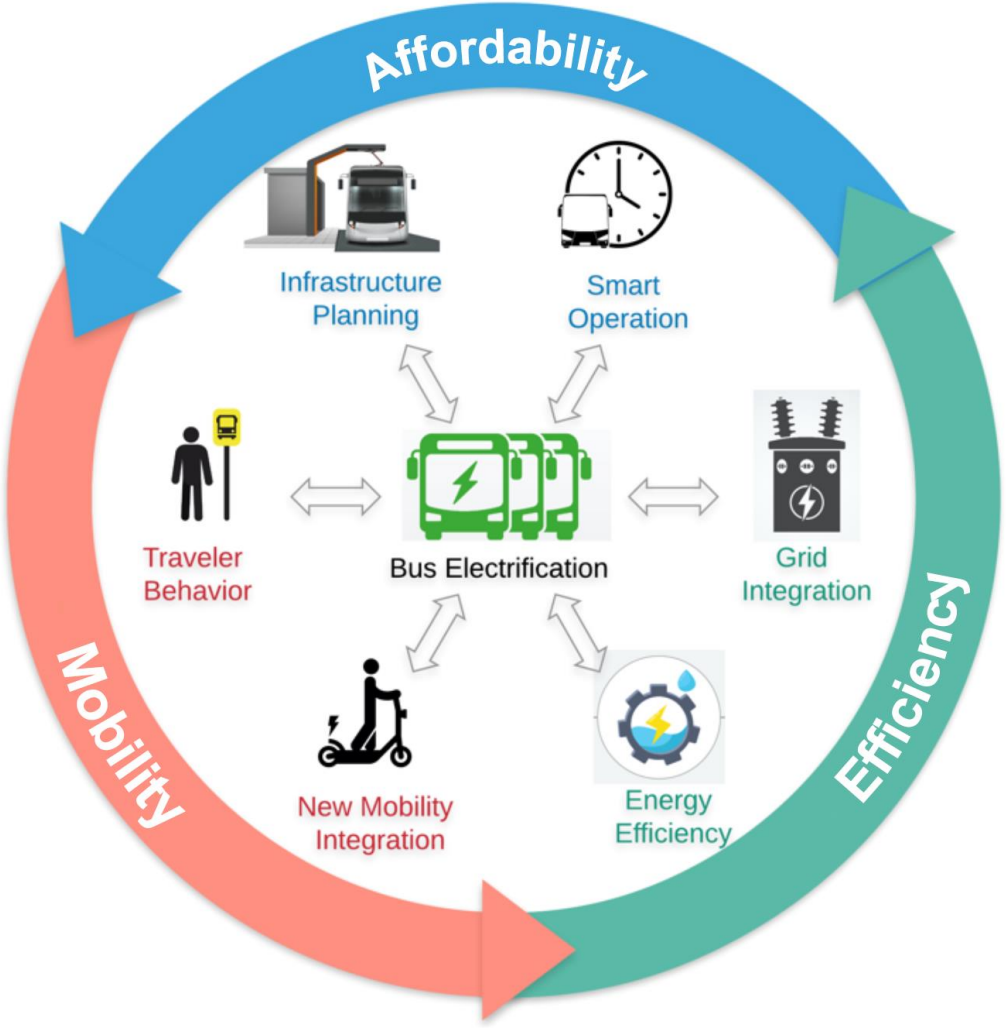


- **Objectives:** to research, develop, apply, and validate technology and/or data solutions to reduce energy costs per mile for battery electric bus systems by ≥ 20% (compared to the non-optimized electrification case), lower up-front battery and charging infrastructure costs by ≥ 10%, and bring down bus charging costs by ≥ 20%.

Milestones

Planned Completion Date	Milestones or Go/No-Go Points	Status
December 2021	RouteE estimator development and training	On Schedule
September 2021	Grid impact analysis commenced	On Schedule
September 2021	Design survey instrument for stated preference experiments	On Schedule
December 2021	Stated preference experiment survey data complete	On Schedule
December 2021	Complete analysis of new mobility options for solving the FM/LM problem	On Schedule
December 2021	Planning and operation model development and testing	On Schedule
December 2022	Initial RouteE-Transit implementation and validation complete	On Schedule
June 2022	Short-term grid impact analysis complete	On Schedule
September 2022	Transit bus improvement strategies identified	On Schedule
September 2022	Inventory of FL/ML strategies and best practices	On Schedule
December 2022	User acceptance of FM/LM options assessed	On Schedule
December 2022	Complete initial implementation and validation of the planning and operation tools	On Schedule

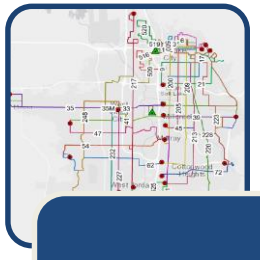
Approach


Affordability
Infrastructure Planning
Smart Operation
Traveler Behavior
Bus Electrification
Grid Integration
New Mobility Integration
Energy Efficiency
Mobility
Efficiency

Task 1: Electric Bus Fleet and Infrastructure Planning

This task will develop a multi-phase, high-fidelity, and large-scale multimodal transit network design tool to determine the optimal transit network configuration, fleet replacement, frequency setting, fare design, battery sizing, and charging facility deployment.

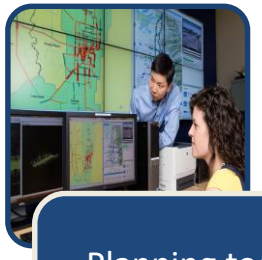
Single-phase model for electric bus system planning



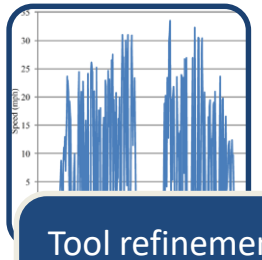
Multi-phase EB planning model

HPC-enabled scalable algorithm development

Energy and environmental baseline establishment



Planning tool refinement based on initial implementation and validation



Tool refinement based on further implementation and validation with real-world data

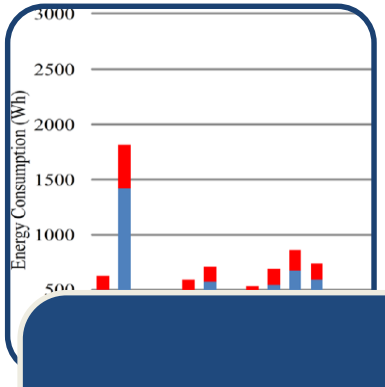
Task 2: Smart Operation of Electric Buses

This task will develop a user-friendly tool to help transit agencies analyze, simulate, and optimize the operation of electric bus systems.

Off-line simulation optimization model for rule-based charging scheduling and management

Dynamic on-line tool for smart charging scheduling and management

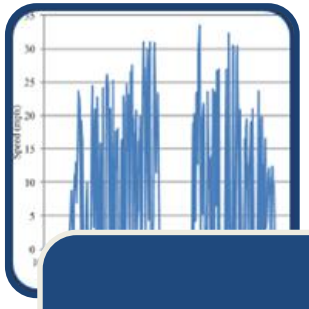
Operation tool refinement based on initial implementation and validation



Operation tool refinement based on further implementation and validation with real-world data

Task 3: Electric Bus Energy Estimation and Optimization

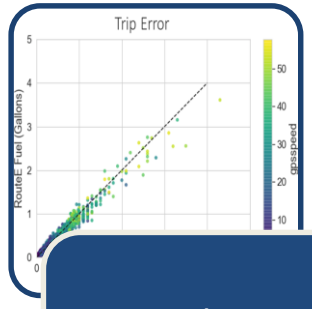
This task will develop a tool to accurately model energy consumption (powered by RouteE) for various bus line and bus powertrain combinations and recommend optimal configurations.



Real-world bus drive cycle data collection

RouteE estimator development and training

RouteE transit customization (RouteE-Transit)



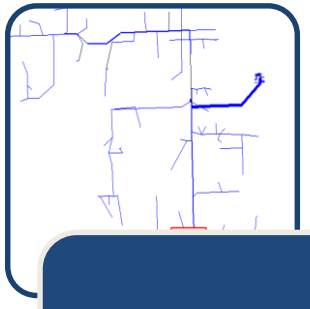
Initial energy estimation and optimization tool implementation and validation

Field Implementation and validation of the RouteE-Transit tool based on real-world data

Task 4: Grid Impact Analysis and Evaluation

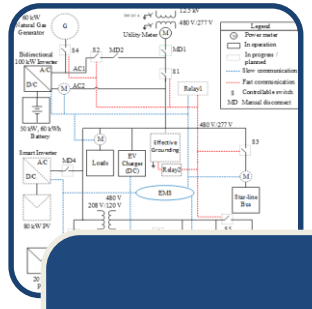
This task will evaluate the impact of the electric bus charging and discharging patterns on the power grid from both operations and economic perspectives, and provide information back to the electric buses fleet operator for fleet scheduling and charging management.

Collect data and setup system for grid impact analysis and evaluation



Short-term spatial and temporal operational impact analysis

Long-term planning impact analysis

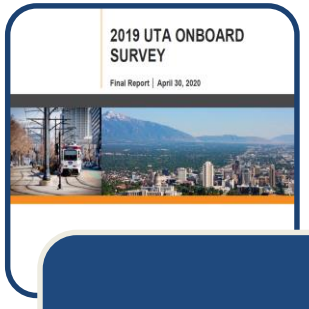


Integration and hardware validation with site level control algorithms

Long- and short-term economic and energy impact analysis

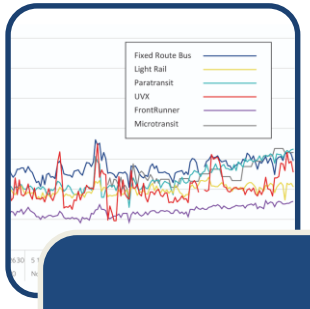
Task 5: Electric Bus User Behavior and Stakeholder Study

This task will analyze electric bus user behavior and stakeholders' preference using a stated preference survey and revealed preference data from transit agencies.



Stated Preference Experiment 1—Bus riders

Stated Preference Experiment 2—General population and Stakeholders



Revealed Preference—Transit agency historical data

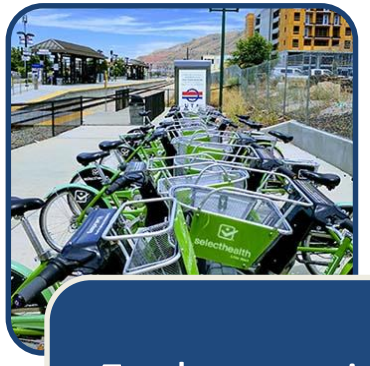
Initial implementation and validation of identified improvement strategies

Field implementation and validation of identified improvement strategies

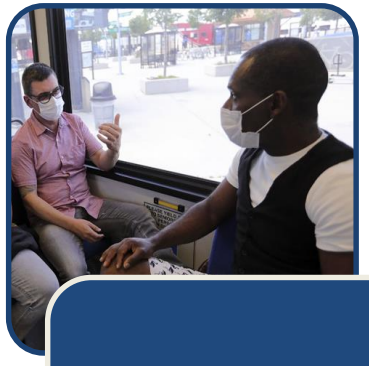
Task 6: New mobility integration for first-mile and last-mile (FM/LM) Connections

This task will model and analyze current and emerging mobility options for solving the FM/LM connection problem for transit bus systems.

Assess FM/LM transportation connectivity to/from stations/stops



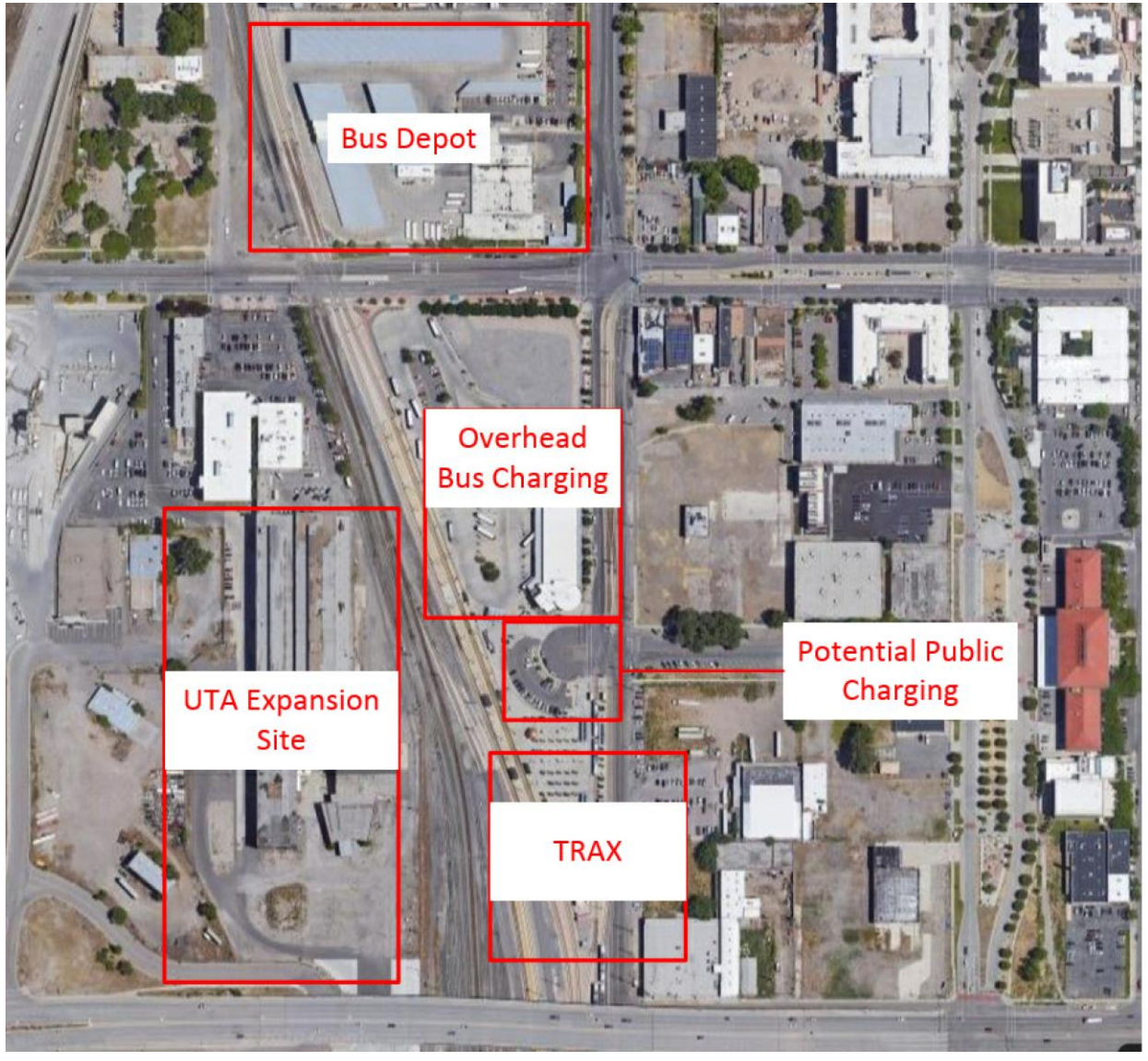
Explore options including new mobility options to solve FM/LM problem



Assess user acceptance of proposed FM/LM options

Design marketing activities in partnership with new mobility providers

UTA Intermodal Hub Site Overview



Technical Accomplishments and Progress

- USU has completed a comprehensive literature review on electric bus fleet/infrastructure planning and operations. The results of the literature review will help the research team better design optimization models/tools for electric bus fleet/infrastructure planning and operations.
- USU and NREL have engaged with UTA to collect bus fuel consumption and bus operation data for establishing energy and environmental baseline and for training FASTSim/RouteE models.
- USU and ANL have started working with UTA and Rocky Mountain Power (RMP) at the UTA Central Station (Intermodal Hub) to collect data for grid impact analysis.
- Purdue and USU have completed a literature review on general EV adoption from a consumer perspective. The research team will start the design of pilot user surveys.
- Purdue has begun a literature review focused on first-mile/last-mile literature and will continue this effort.

Responses to Previous Year Reviewers' Comments

- This project started in February 2021 and it was not reviewed last year.

Collaboration and Coordination with Other Institutions

Utah State University	• Electric bus fleet and infrastructure planning, smart operations • Grid impact, UTA intermodal hub implementation • New mobility integration
NREL Transforming ENERGY	• Energy planning and optimization tool, RouteE customization • Machine learning based energy estimation • HPC-enabled scalable algorithm development
Argonne National Laboratory	• Grid impact analysis and evaluation
Purdue University	• Electric bus user behavior and stakeholder study • First-mile last-mile connections
UTA	• Field data collection • Implementation support
TriMet	• Field data collection • Implementation support
PacifiCorp	• Grid analysis • Implementation support

Remaining Challenges and Barriers

- Covid-19 disrupted normal transit operations and may delay the proposed transit user surveys. Hybrid survey methods (on-line and in-person) may be adopted.
- Energy consumption uncertainty of electric buses is not well understood.
- Reliability issues associated with electric buses and charging equipment may pose challenges for field implementations. However, these issues are expected to be resolved soon as products get more mature and transit agencies are more experienced with operating electric buses.

Proposed Future Research

- FY 2021: Technology and Strategy Development; Data Collection and Analysis
  - Develop single-phase and multiple-phase models for electric bus system planning
  - Develop off-line and dynamic models for smart charging scheduling and management
  - Real-world drive cycle data collection and RouteE estimator development and training
  - Collect data and setup system for grid impact analysis and evaluation
  - Explore new mobility options for solving the FM/LM problem
- FY 2022: Technology and Strategy Refinement with Initial Implementation and Validation
  - Initial implementation and validation of proposed models and tools with large-scale numerical experiments
  - Complete stated preference experiments
  - Analyze short-term spatial and temporal operational impact on power grid
  - Conduct revealed preference study based on transit agency historical data

Any proposed future work is subject to change based on funding levels.

Summary

- The end of project goal is to promote the large-scale adoption of electric buses and improve the efficiency and effectiveness of transit bus systems, which aligns with EEMS's overall goal.
- The holistic modeling and tool development framework for promoting transit bus electrification focuses on the perspectives of efficiency, affordability, and mobility.
- This project will develop a set of innovative planning and operation tools and identify improvement strategies to help transit agencies gradually and effectively deploy and operate electric buses.